Unmanned Aircraft Systems Overview

A Discussion On System Design And Operations

NTSB Forum on Safety
Of Unmanned Aircraft Systems
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Northrop Grumman Corporation

Outline

NORTHROP GRUMMAN

- **Not “ALL” UAS Are Alike**
- UAS – Integrated System Overview
- Autonomous, Redundant, Reliable, and Robust Architecture
- Reliability & Safety In Development, Manufacturing And Operations
- Summary And Closing Thoughts

Wide Range Of UAS Missions, Sizes and Capabilities

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- UAS < 50 Pounds
- Flight Performance
  - **Cruise speeds 20-50 mph, increasing with weight**
  - **Working altitudes 150'-1000' AGL**
  - **Flight endurance up to 5+ hours**
- Operations
  - **Airspace - class B-G**
  - **Hand launched from anywhere**
  - **Recovered anywhere**
  - **Op Radius about 10 miles**
- Equipage
  - **Limited Payload Capacity**

- 100 lbs < UAS < 3,000 lbs
- Flight Performance
  - **Cruise speeds 70 to 220 knots**
  - **Working altitudes to 25k feet**
  - **Flight endurance up to 20+ hours**
- Operations
  - **All airspace classes**
  - **Generally use a rolling takeoff and landing**
  - **Some vertical takeoff/landing**
- Equipage
  - **All use GPS with an autopilot**
  - **All have payload capacity for other electronic equipment**

- UAS > 10,000 lbs
- Flight Performance
  - **Cruise speeds 210 to 500+ knots**
  - **Working altitudes to 65k feet**
  - **Flight endurance up to 50 hours**
- Operations
  - **Airspace - class A to G**
  - **Paved Runways, Towered Airports Used to Launch/Recover**
  - **Operating Radius out to 4,000+ nmi**
- Equipage
  - **CNS/ATM Compliant**
  - **Large Payload Capacities**

INCREASED COMPLEXITY AND LEVELS OF AUTONOMY

UAS Spectrum As Diverse As Manned Aviation

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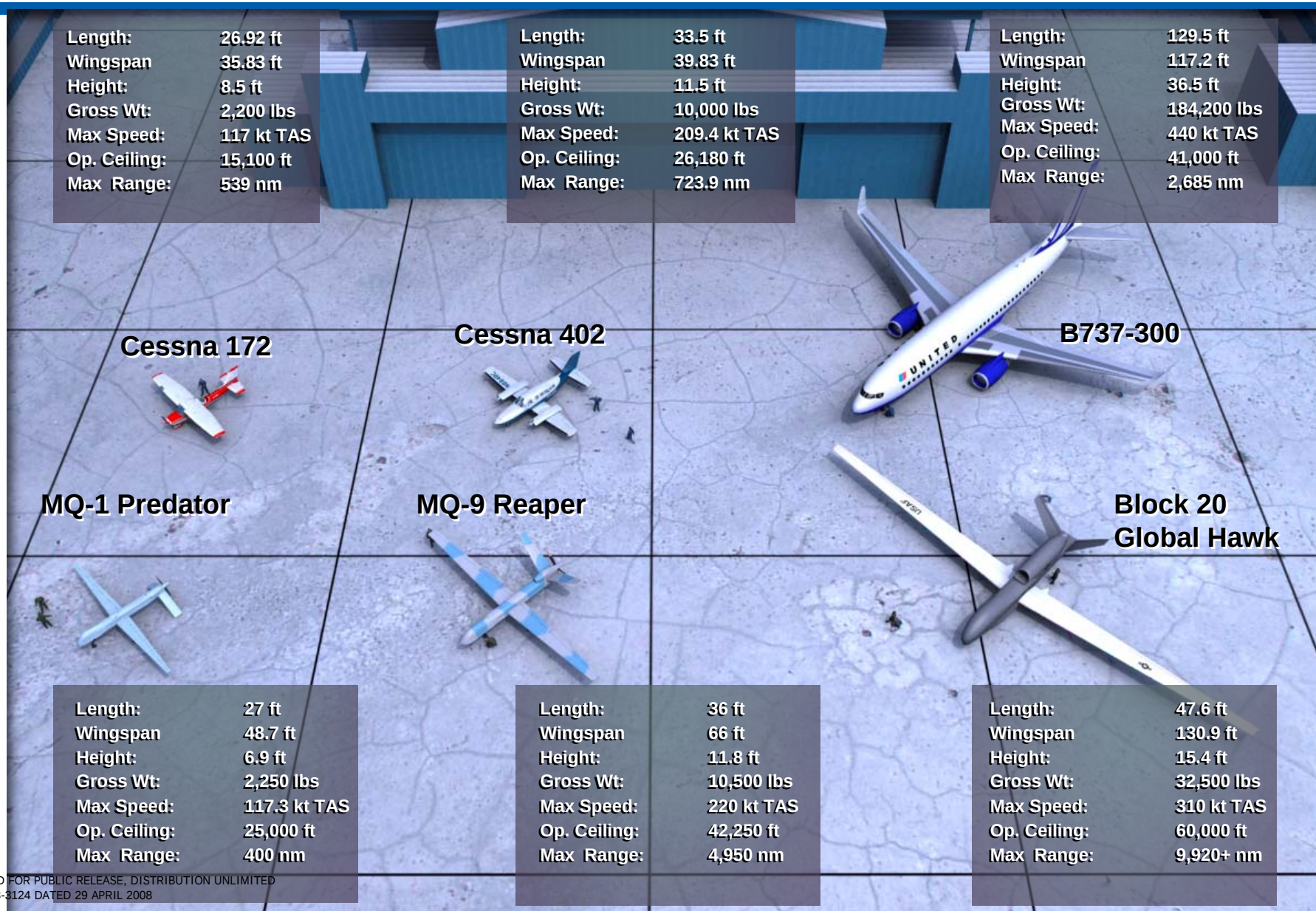

NG UAS Portfolio
A Strong Legacy In History And Experience

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Fundamental UA System Elements For A Safe And Robust Architecture

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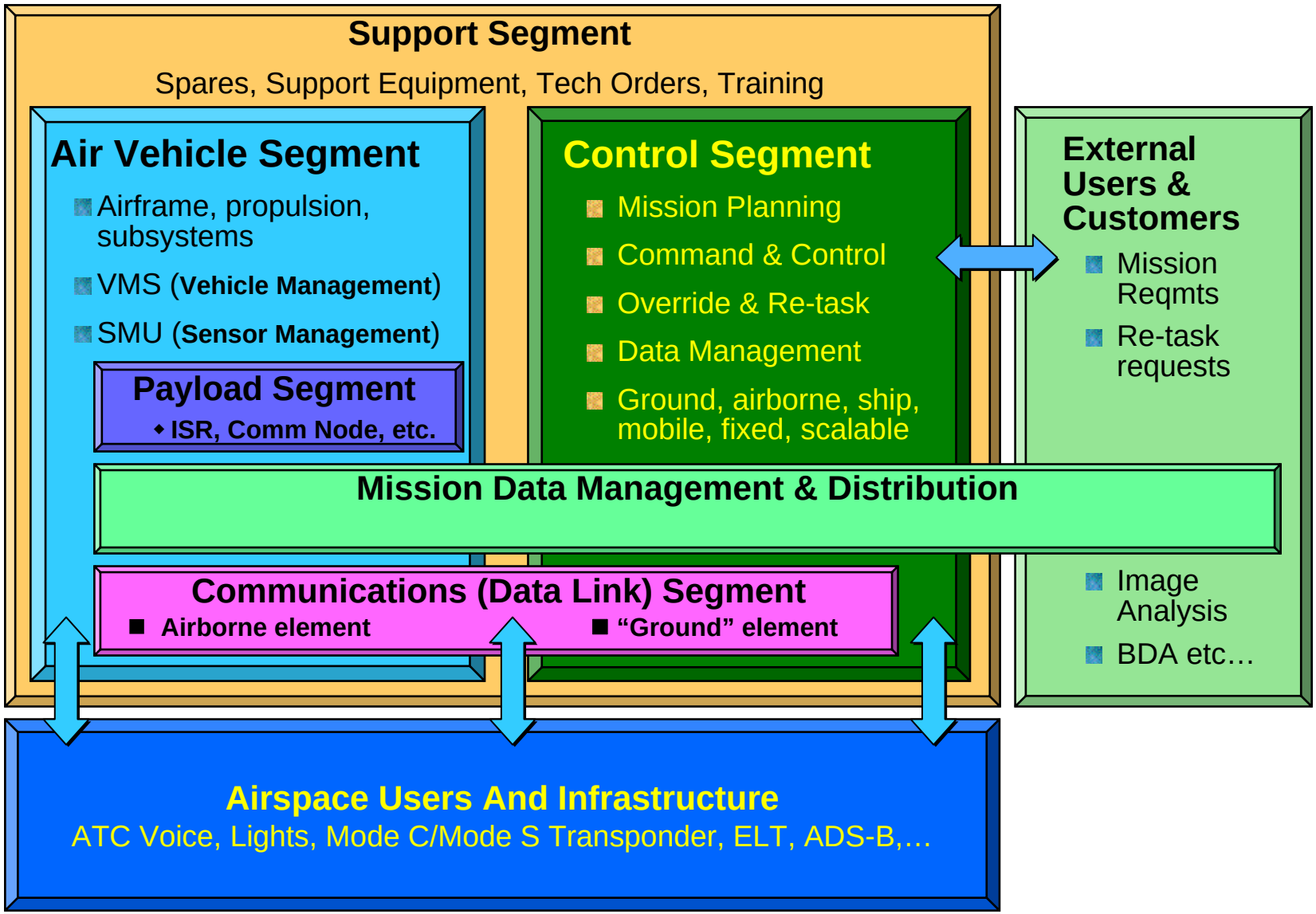

All UAS Elements Form An Integrated System

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Air Vehicle
(Airframe & Subsystems)

Payloads
(SAR, EO/IR, etc.)

DataLink/Communications Systems

Launch & Recovery
Element (LRE)

Mission Planning

Mission Control
Element (MCE)

Support Segment
(Tech Data, Spares, GSE, Training…)

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Redundant Data Links Tie Aircraft To Pilots In Ground Control Stations

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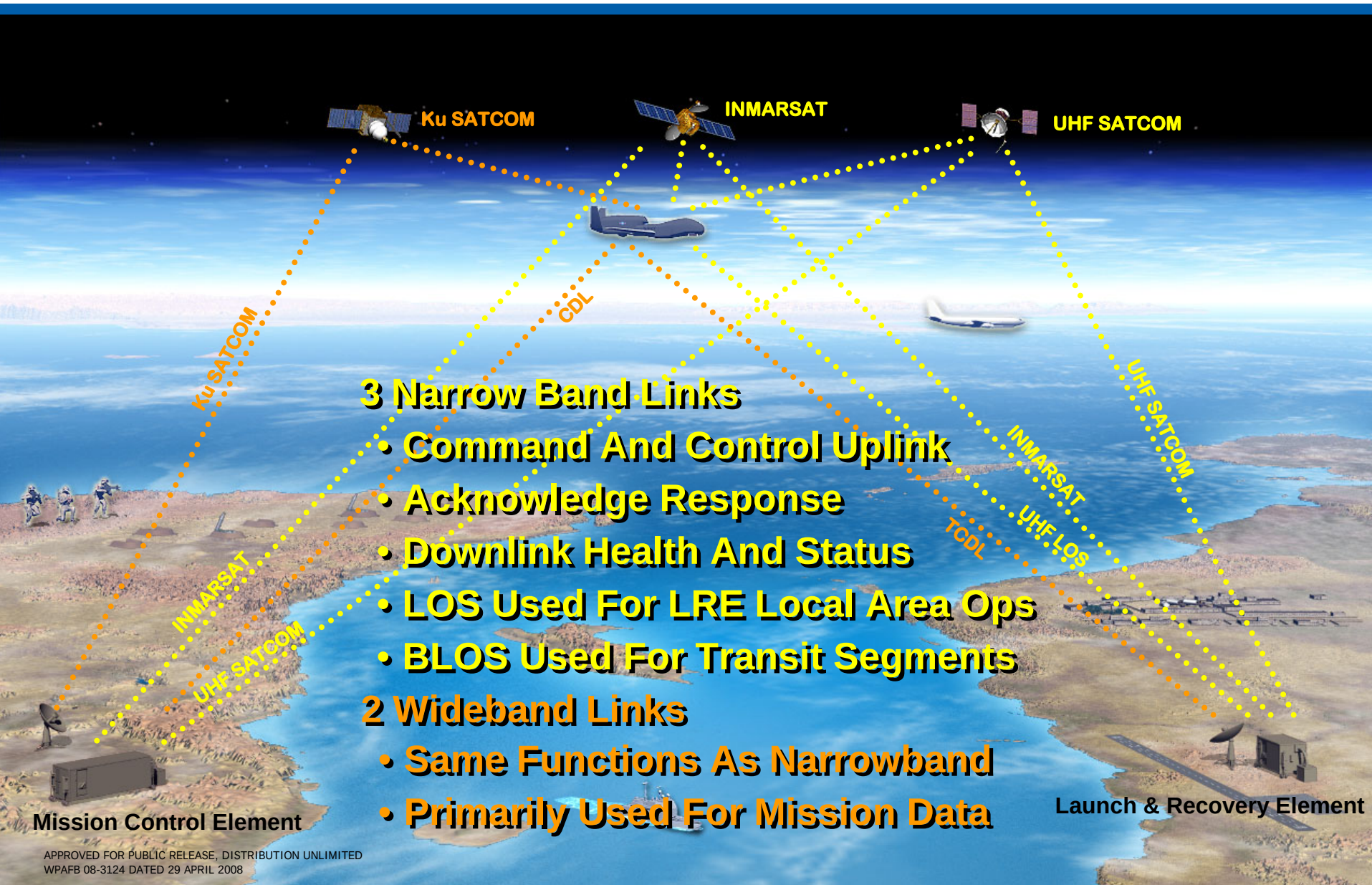

Launch and Recovery Element

- Located At Operating Base For Ground Ops, Takeoffs And Landings
- GH Pilot Commands Execution Of Mission
  - Sys Configuration & Start-Up
  - Taxi, Takeoff & Climb
  - Descent & Landing
- Communicate/Coordinate With ATC
- Issue Commands, Monitor UAV Operation And Systems Status
- Execute Override Commands As Required

Mission Control Element

- Located Anywhere Within Satcom or Terrestrial Feed Footprint
- GH Pilot Commands Execution Of Mission
  - Issues Commands And Monitors UAV Systems Operation & Status
  - Communicates And Coordinates With ATC and Other Users/Agencies
  - Coordinates Changes To Mission Plan

- Sensor Operator Monitors Payload Operation
  - Coordinates External Requests
  - Provides Collection Retasking Commands
  - Reviews Imagery Quality

Aircraft Flies To Pre-Planned Mission Route

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- Mission Plan Waypoints (GPS LAT/LON/ALT) Define Primary, Contingency, And Alternate Routes
- Contingency Routes Pre-Coordinated And Created Within Mission Plan
  - Loss of Communications (Data-Link)
  - Loss Of Redundancy Malfunctions
  - Engine Out Or Immediate Landing / Ditch
  - Land Abort / Go Around
- Action Points Invoke System Tasks (Gear Up, Gear Down, Light On, Lights Off, Satellite Selection, Freq Settings, etc.)

Autonomous System Operation And A Fully Defined Mission Plan Allows Pilot To Focus On Managing The Mission

Pilot Controls UAS Through Robust Set Of Commands And Overrides

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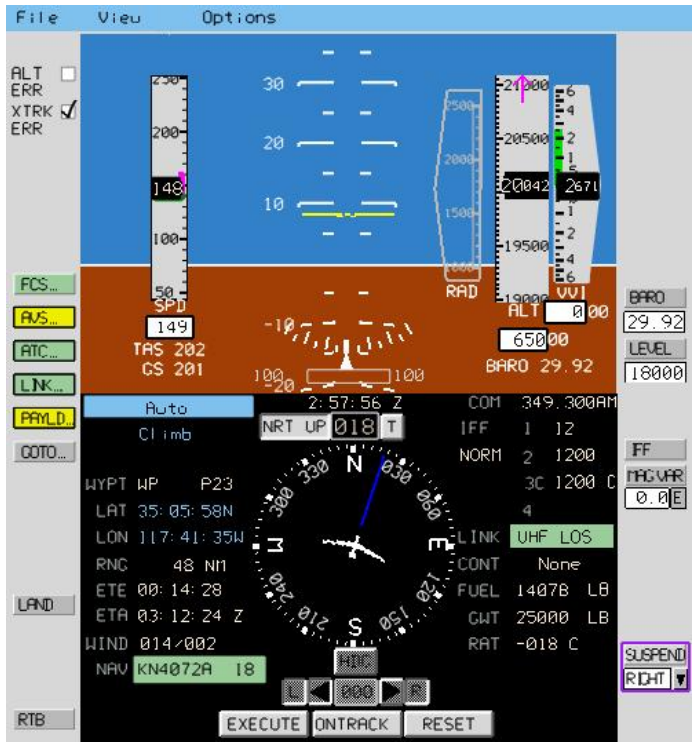
- Commands Entered Via Mouse And Keyboard
  - Functions Selected From HCI Display Buttons Or Menus
  - Confirm Action Required To Execute Function
- Commands Entered To Configure And Activate Desired Functions
  - Comms Set-Up And Utilization (Primary Link, Freq Sets, Etc.)
  - Nav Lights On/Off, Strobes On/Off, Gear Up/Down, Transponder Codes, etc.
- Manual Flight Control Provided Through Override Commands
  - Airspeed Increase/Decrease, Altitude Hold/Change, Turn/Heading Change, Go To Different Waypoint, Climb/Descent Rate Change, etc.
  - Override Of Autonomous Contingency Responses
    - Landing Site and Runway Selection
    - Override Decision And Continue On Mission

Robust Set Of Selectable Commands Provide Pilot With Control Of System With Minimal Use Of Precious Control Link Bandwidth

Continuous Updates Of System Status For Situational Awareness

- Aircraft Reports State Of system To Pilot
- Health and Status Data Downlinked And Displayed At 1 Hz And 1/5 Hz
- Cautions / Warnings, and Significant Events Displayed In Primary Flight Display And In Advisory Windows
- Additional Detailed Reports Of Subsystem Status Downlinked On Command
- Heartbeat Function And Stale Data Meter Detect Dropouts Or Loss Of Link



Primary Flight Display Uses Familiar Cockpit Symbology Taking Advantage Of Human Factors Standards Developed For Manned Aircraft

System Enables Voice Comms Between Pilot And ATC Or Users Via Multiple Means

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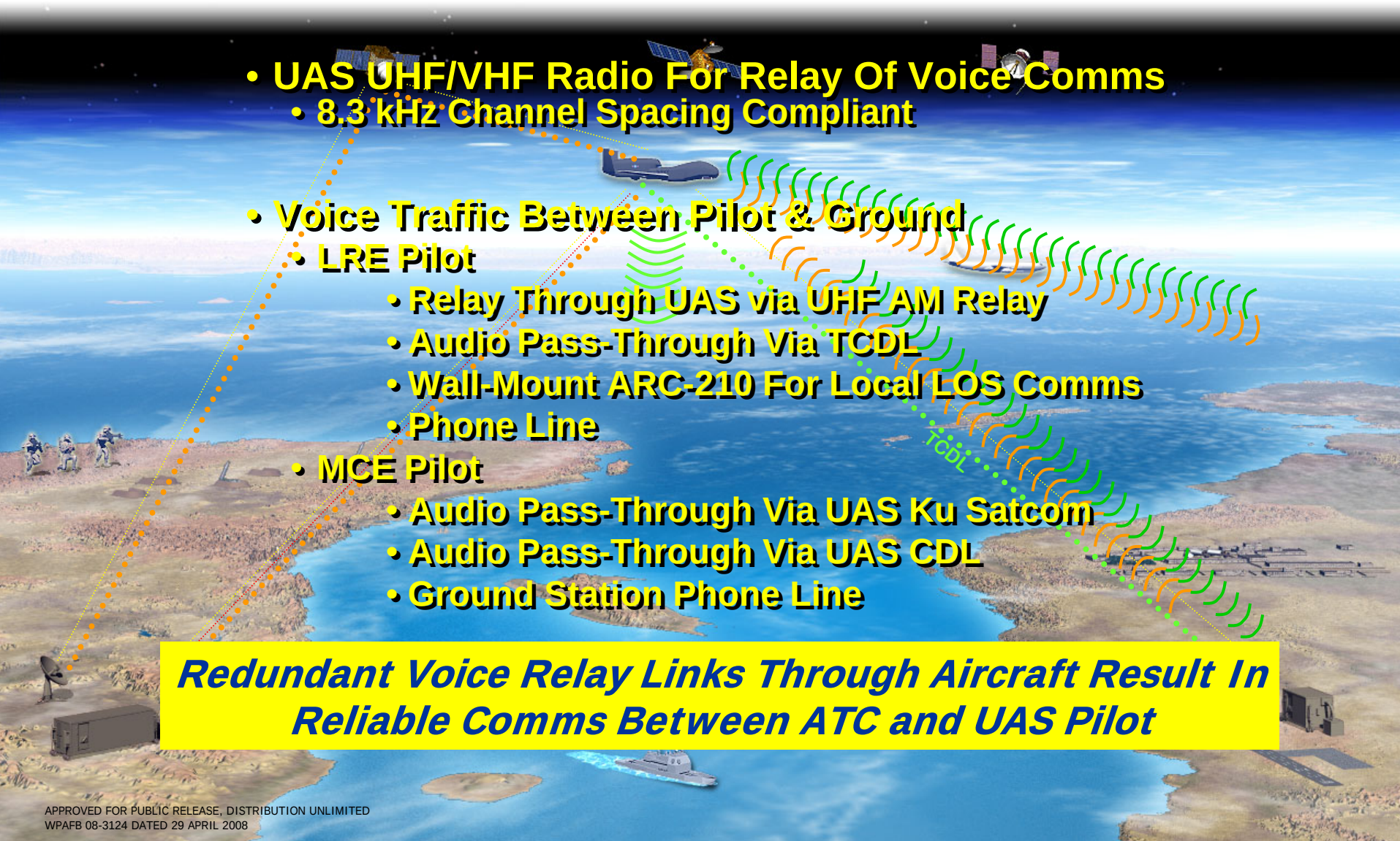

- UAS UHF/VHF Radio For Relay Of Voice Comms
  - 8.3 kHz Channel Spacing Compliant
- Voice Traffic Between Pilot & Ground
  - LRE Pilot
    - Relay Through UAS via UHF AM Relay
    - Audio Pass-Through Via TCDL
    - Wall-Mount ARC-210 For Local LOS Comms
    - Phone Line
  - MCE Pilot
    - Audio Pass-Through Via UAS Ku Satcom
    - Audio Pass-Through Via UAS CDL
    - Ground Station Phone Line

Redundant Voice Relay Links Through Aircraft Result In Reliable Comms Between ATC and UAS Pilot

Fully Autonomous And Highly Predictable Aircraft Operation

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- Dual Flight Computers Control Flight And Manage System Functions
  - Flight Computers Are Synchronized To Each Other
  - Aircraft Sensors And Systems Are Cross Strapped To Each Flight Computer
- Aircraft Flight And Subsystems Management Performed Autonomously
  - No Joystick, No Throttle, No Pedals
- All Phases Of Flight Performed Autonomously
  - Key Pilot Decisions/Authorization Points Included Within Mission Plan (Authorize Entry To Active Runway, Takeoff, Taxi Off Into Taxiway, etc.)
- Aircraft Operational State Determined and Maintained Onboard Aircraft And Reported To Pilot In Ground Station
  - Maintains Safe Flight Regardless Of Ground Station Malfunctions Or Lost Control Link

Deterministic, Rules Based Logic For System Operation Results In A Highly Predictable System That Performs In A Known And Consistent Manner

Safe And Reliable Operation Via Redundant Flight Critical Systems And Critical Components

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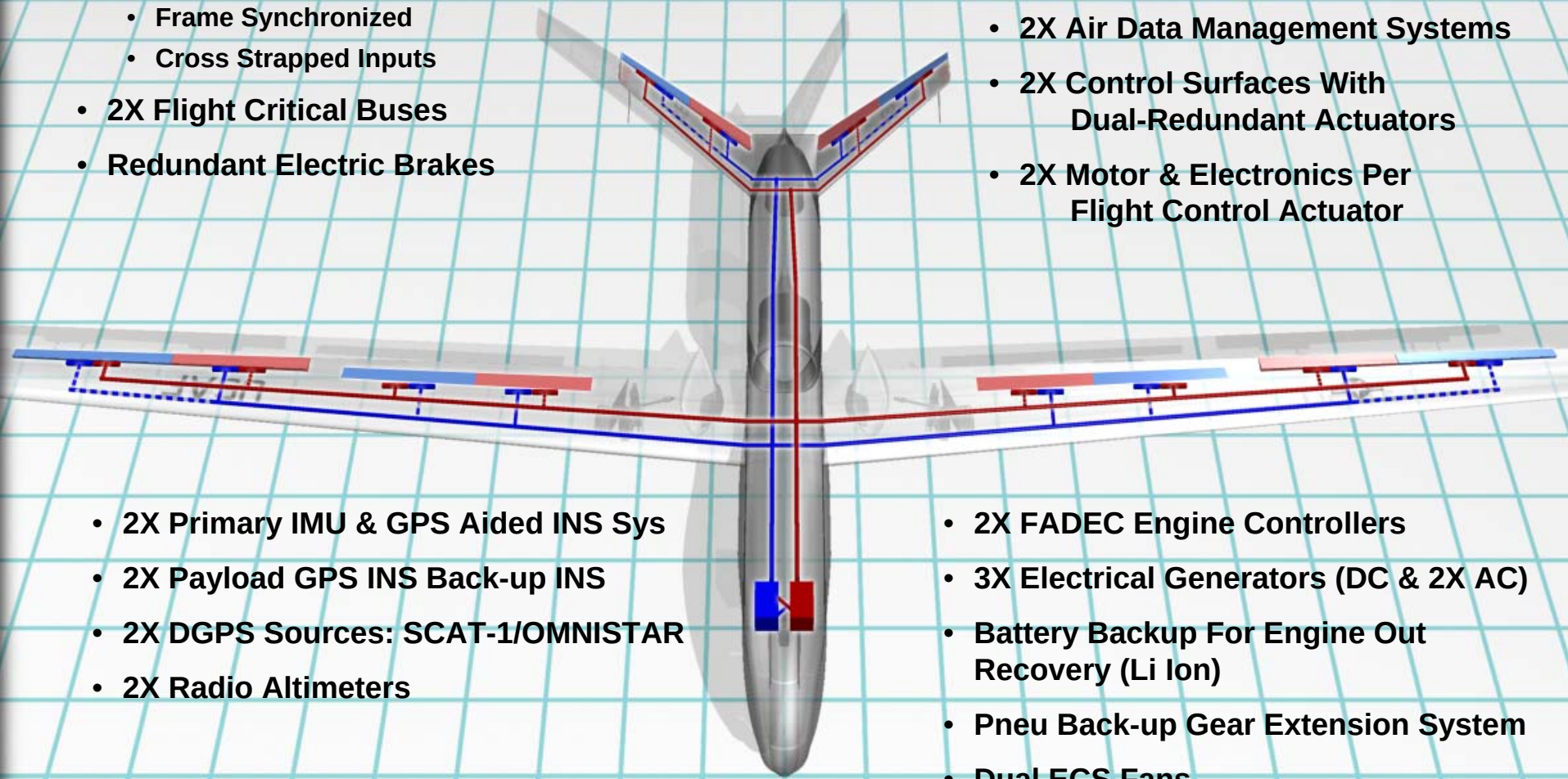
- 2X Flight Computers (IMMC)
  - Frame Synchronized
  - Cross Strapped Inputs
- 2X Flight Critical Buses
- Redundant Electric Brakes

- 2X Pitot Static Air Data Systems
- 2X Air Data Management Systems
- 2X Control Surfaces With Dual-Redundant Actuators
- 2X Motor & Electronics Per Flight Control Actuator



- 2X Primary IMU & GPS Aided INS Sys
- 2X Payload GPS INS Back-up INS
- 2X DGPS Sources: SCAT-1/OMNISTAR
- 2X Radio Altimeters

- 2X FADEC Engine Controllers
- 3X Electrical Generators (DC & 2X AC)
- Battery Backup For Engine Out Recovery (Li Ion)
- Pneu Back-up Gear Extension System
- Dual ECS Fans

Subsystem Malfunctions Detected And Reported Autonomously

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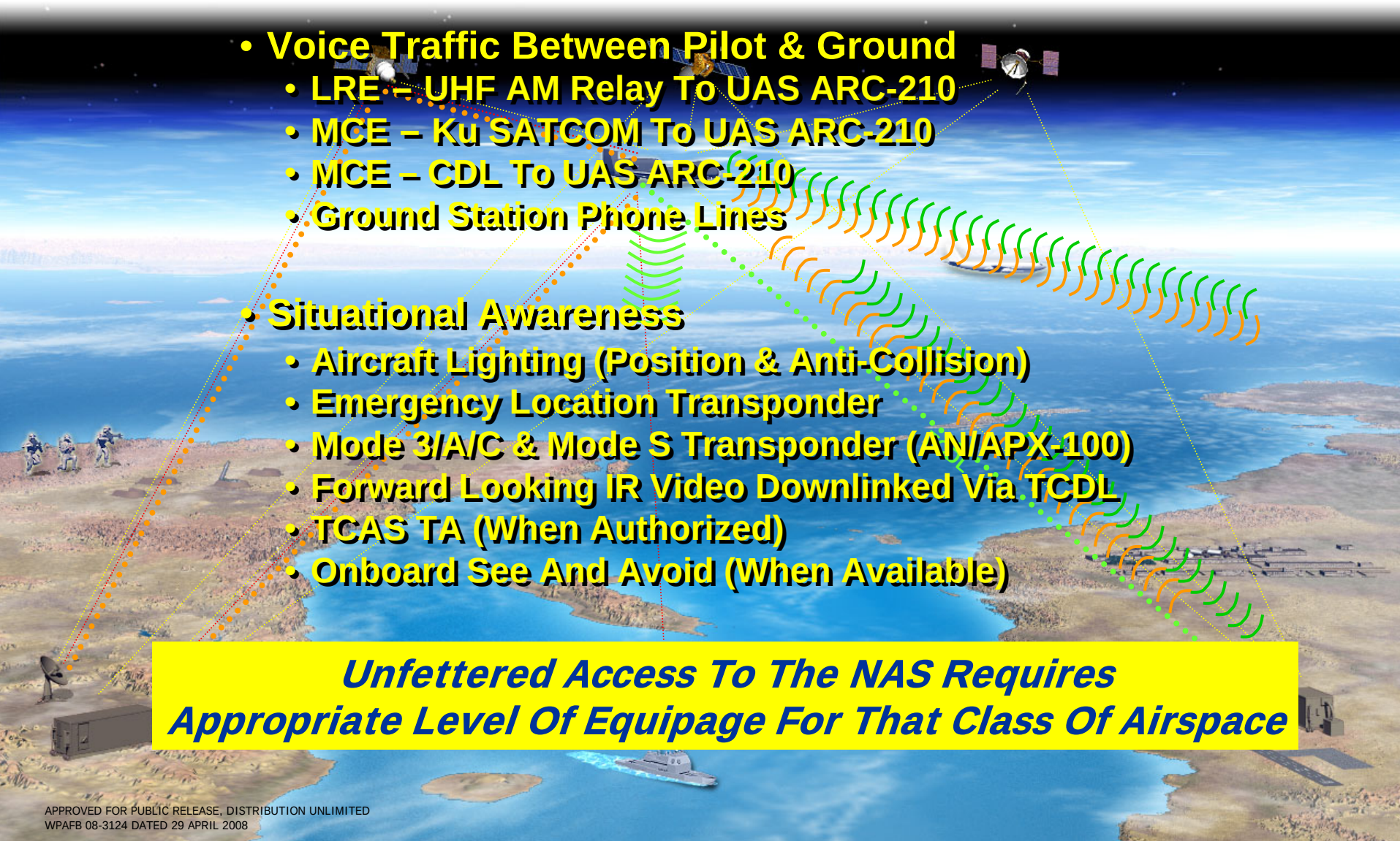
- Nominal Operation Monitored By On-Board Systems Continuously
  - Realtime Comparison To Performance Models
  - System Monitors Operation Within Allowed Limits And Rates Of Change To Determine Anomalies
- Malfunctions Detected By Sensor/Component Data, CBIT, and Model Discrepancies
- System Designed For Graceful Degradation
  - Announce Non-Critical Exceedances
  - Determine Failures And Disable Malfunctioning Component Or String
  - Invoke Use Of Backup Systems
  - Last Man Logic
- Invoke Change In State (Contingency Level) And Execute Pre-Planned RTB, Emergency Landing, Or Go-Around Depending On Severity Of Fault

Autonomous Fault Detection And Fault Management Are Critical To UAS Operation In Absence Of Control Link

Aircraft Configured With Systems And Equipment For Integration Into The Airspace



- **Voice Traffic Between Pilot & Ground**
  - LRE – UHF AM Relay To UAS ARC-210
  - MCE – Ku SATCOM To UAS ARC-210
  - MCE – CDL To UAS ARC-210
  - Ground Station Phone Lines
- **Situational Awareness**
  - Aircraft Lighting (Position & Anti-Collision)
  - Emergency Location Transponder
  - Mode 3/A/C & Mode S Transponder (AN/APX-100)
  - Forward Looking IR Video Downlinked Via TCDL
  - TCAS TA (When Authorized)
  - Onboard See And Avoid (When Available)

Unfettered Access To The NAS Requires Appropriate Level Of Equipage For That Class Of Airspace

Equipment For Position, Identification, And Situational Awareness

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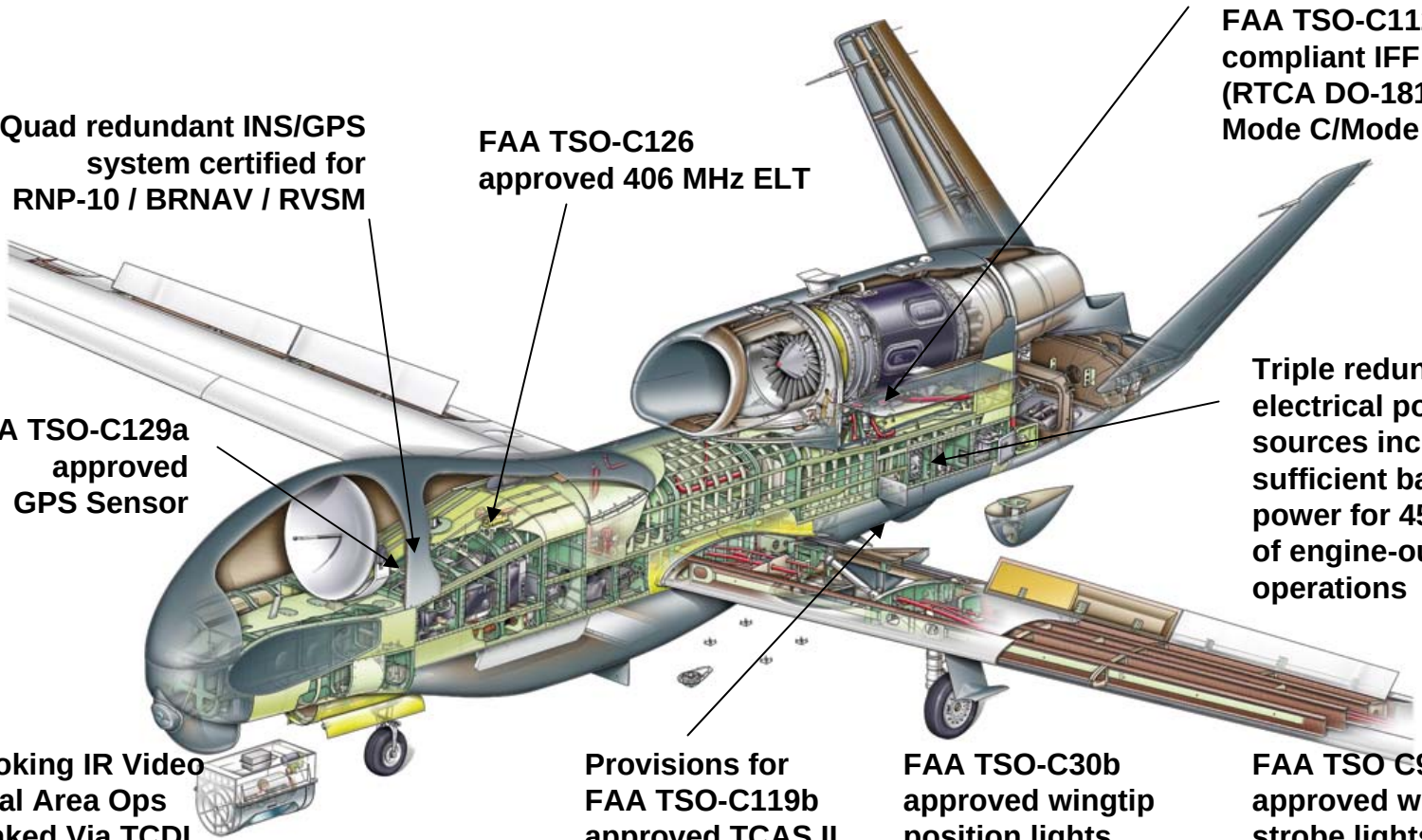
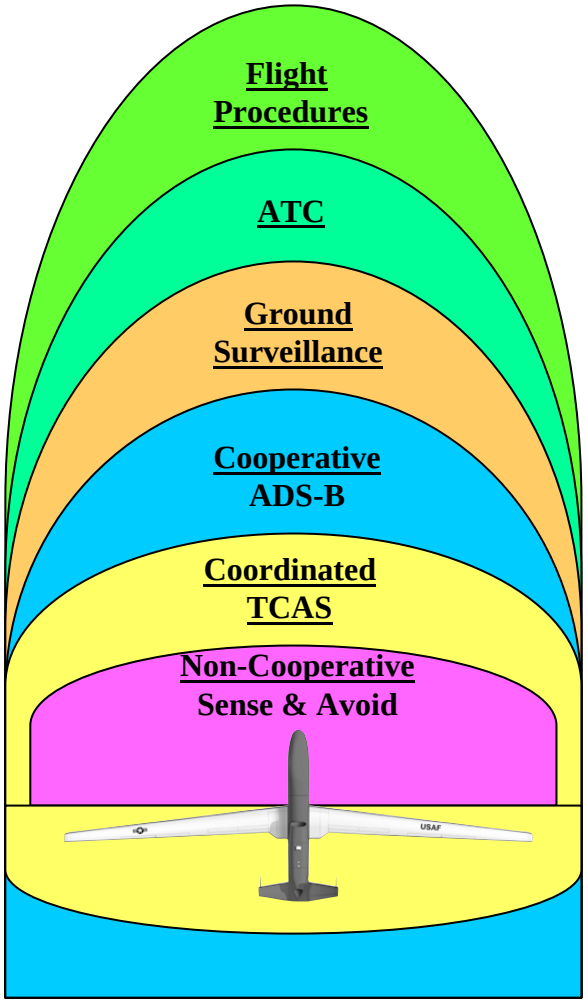


Collision Avoidance Safety 'Layers' Under Study For Incorporation Into UAS



Flight Procedures		
Type Flight	**Track**	**Required Altitude**
VFR	Eastbound	Odd Thousand feet + 500 feet
	Westbound	Even Thousand feet + 500 feet
IFR	Eastbound	Odd Thousand feet below 18,000 ft Odd Flight Level Below 29,000
	Westbound	Even Thousand feet below 18,000 ft Even Flight Level Below 29,000

ATC: Route clearances (track and altitude), traffic information and vectoring if potential collision threat and undetected by aircrew

Ground Surveillance: Ground RADAR augmented by interrogating AC transponders and integrating their response into the radar display to the controller. FAA adding receipt of ADS transmissions and will broadcast on TIS-B

ADS-B: 1090 ES version expected to provide 40 NM range in high density environments and 90 NM range in low density environments

TCAS: RA- Vertical maneuver command coordinated with other TCAS equipped AC, typically 25 to 45 seconds before CPA
TA – Advisory of existence and location of intruder AC, range to 40 NM

SAA: Correlates and fuses inputs from SAA sensors, TCAS, ADS to alert pilots of intruders, potential collision threats, and provide recommended evasive maneuvers to be executed autonomously. (Performs SEE & AVOID function required by 14 CFR 91.113)

RTCA Standards Applicable to Our UAS

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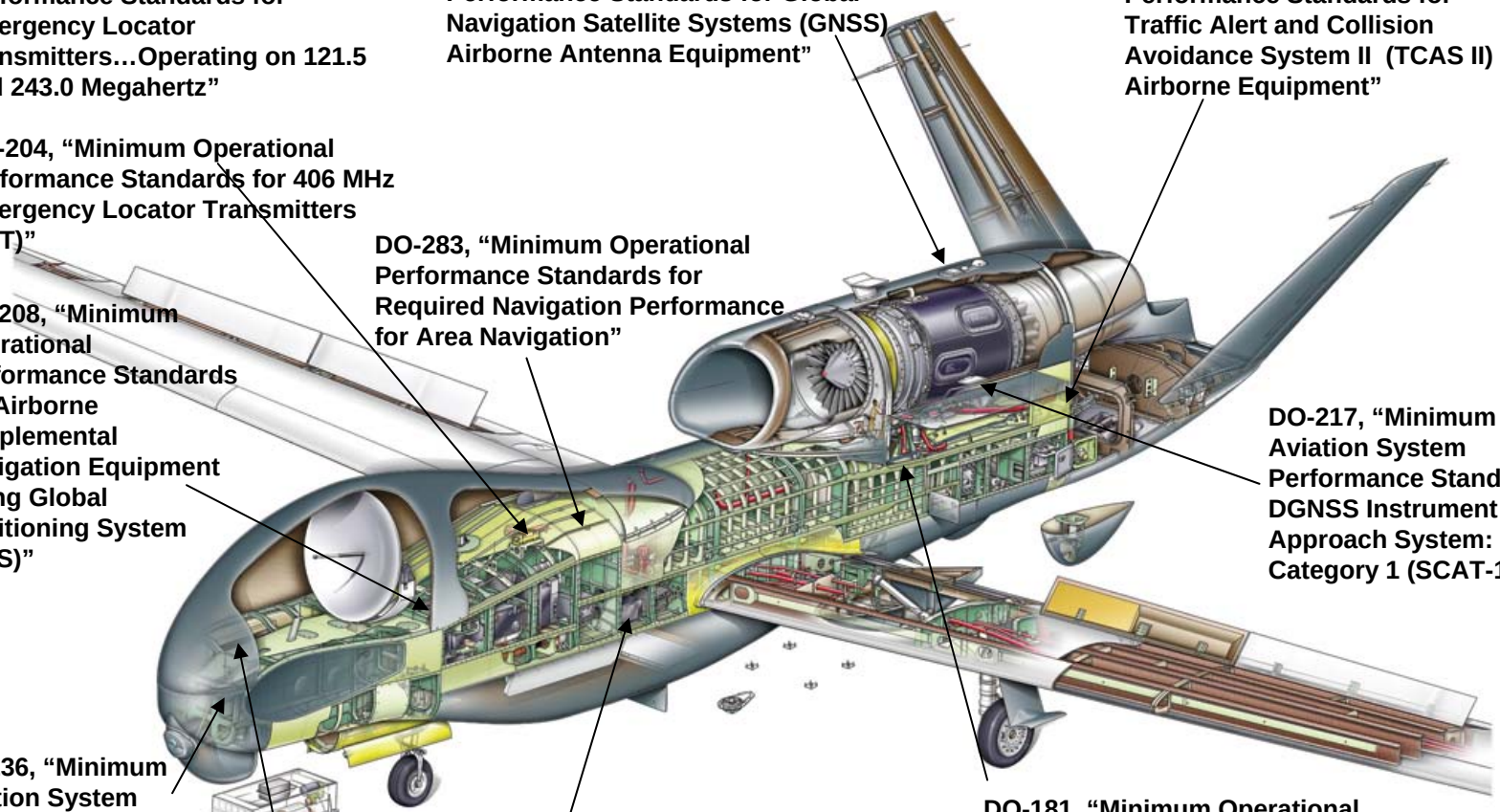

DO-183, "Minimum Operational Performance Standards for Emergency Locator Transmitters…Operating on 121.5 and 243.0 Megahertz"

DO-228, "Minimum Operational Performance Standards for Global Navigation Satellite Systems (GNSS) Airborne Antenna Equipment"

DO-185, "Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment"

DO-204, "Minimum Operational Performance Standards for 406 MHz Emergency Locator Transmitters (ELT)"

DO-283, "Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation"

DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)"

DO-217, "Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category 1 (SCAT-1)"

DO-236, "Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation"

DO-178 "Software Considerations in Airborne Systems and Equipment Certification"

DO-181, "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment"

DO-160 "Environmental Conditions and Test Procedures for Airborne Equipment"

DO-235, "Assessment of Radio Frequency Interference Relevant to the GNSS"

DO-304, "Guidance Material and Considerations for Unmanned Aircraft Systems"

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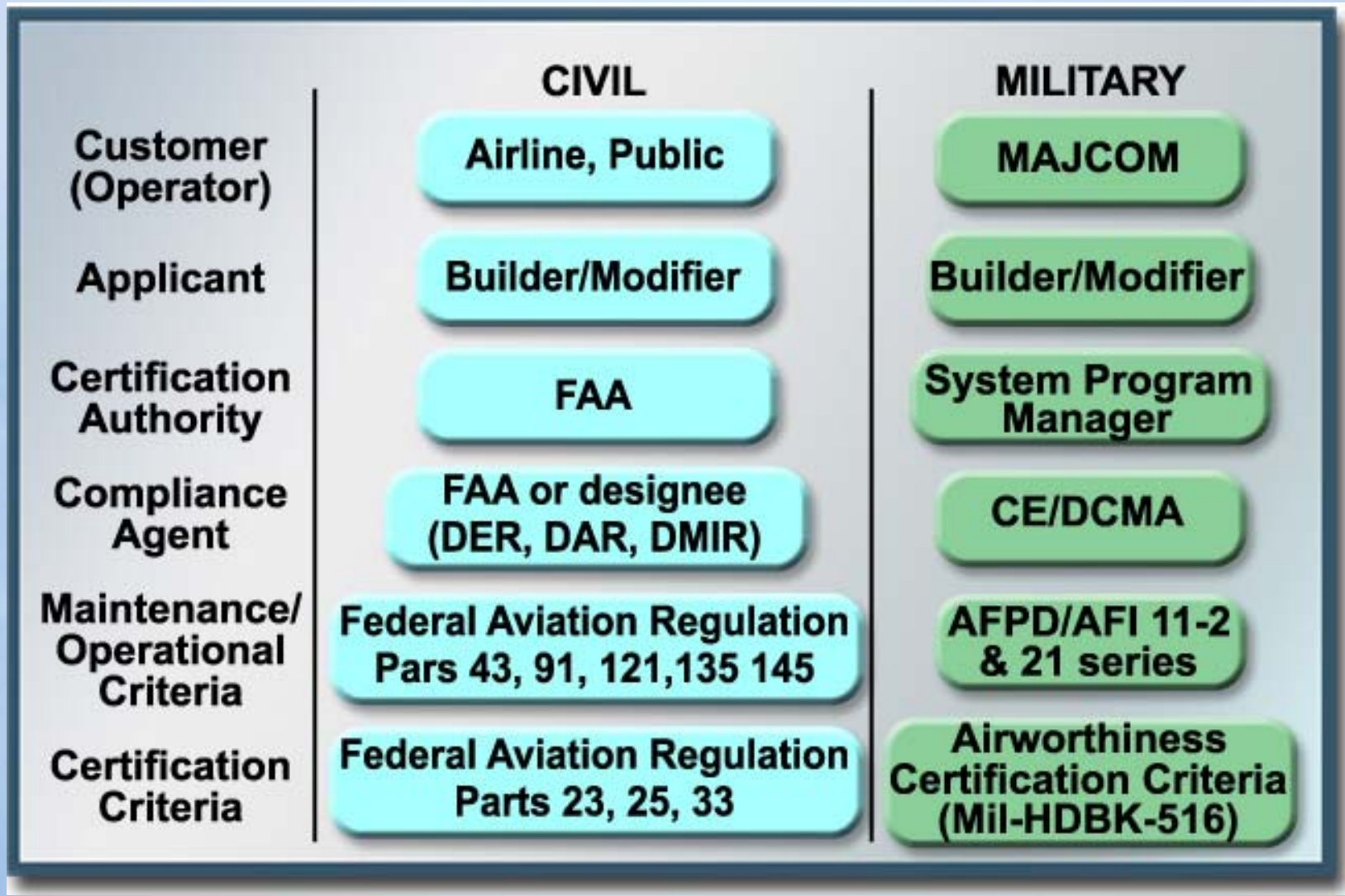
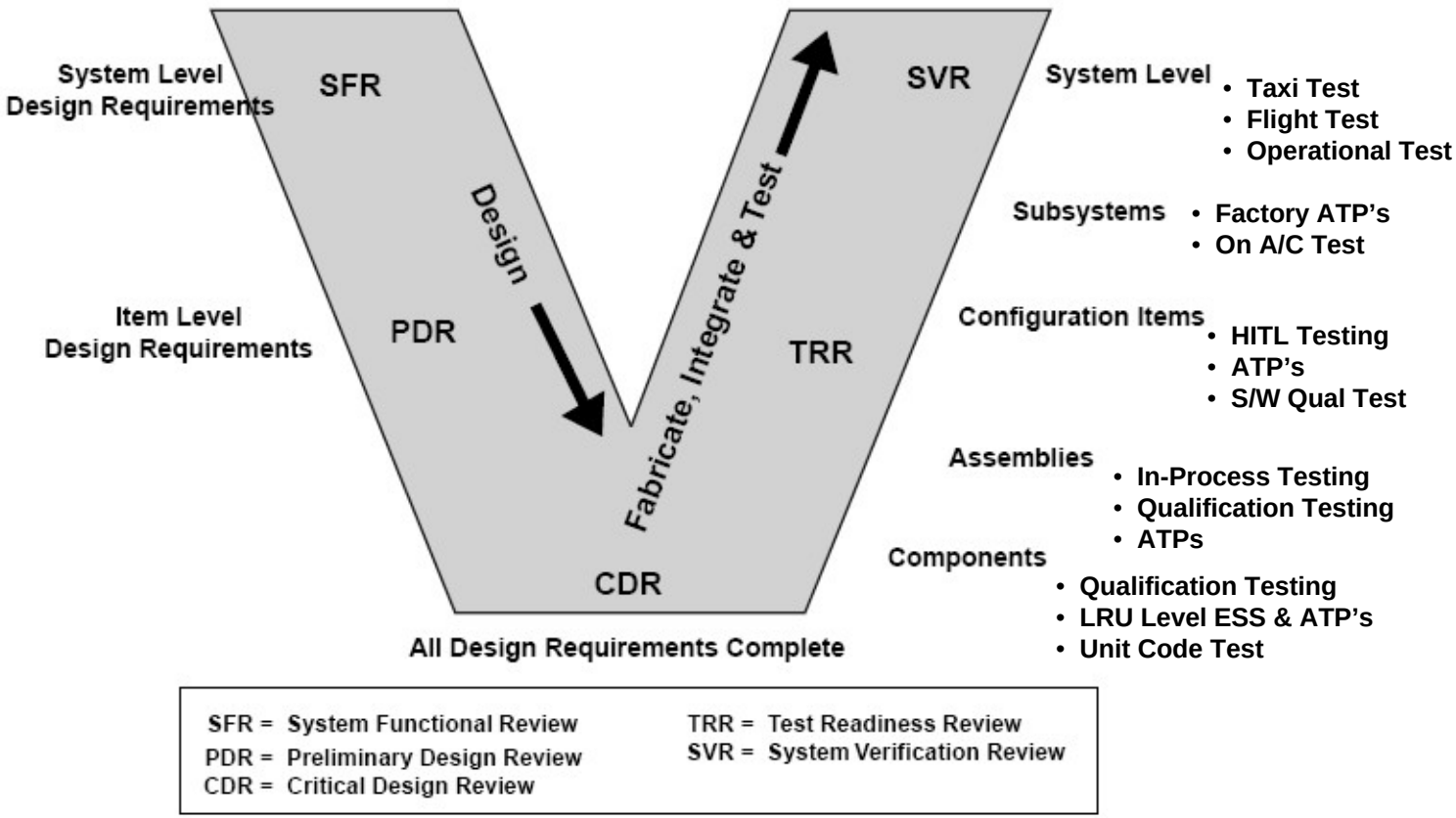
Relationships In Civil & Military Terms



System Developed Using Classical SE Methods



SOURCE: Systems Engineering Fundamentals, DoD Systems Management College

Robust End to End HW/SW System Integration

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Global Hawk
System Center

X-47B UCAS
System Center

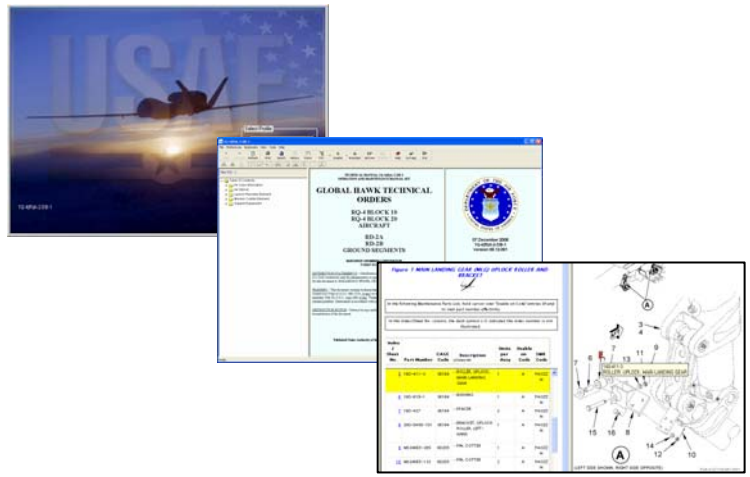
Fire Scout
System Center

VMS Lab

...Key to Success to Date

Documentation For Maintenance And Flt Ops Developed To Military Standards

- Tech Orders Created For Maintenance And Operations
  - Electronic Flight Manual, Emerg Procedures, And Maintenance Procedures
  - Validation and Verification Conducted By USAF Personnel



- Ground Support Equipment Designed And Produced To Military Standards

- Formal Training Program In Place For Flight Crew Operation
  - Academics And Computer Based Training
  - Part Task Trainer Simulations
  - Basic Qualification Training
  - Continuation Training
  - Instructor Pilot Upgrade

U.S. Air Force Photo / Stacey Knott

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Summary and Closing Thoughts

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- Complex Systems Designed Using Classical Aerospace Systems Engineering Processes...
- Based On Manned Aircraft Standards, Tailored For Particularities Of UAS'
- Certified To MIL-HBK-516

- Autonomy And Predictability Are Key Attributes Of Sophisticated UAS'...
- Enabled Through Redundancy And Reliability Within Architecture...
- With Rules Based Logic Designed For Graceful Degradation

- System Architecture And Equipment Enables Pilot To Interact With The Existing Airspace Infrastructure And To Integrate Future Functionality Upgrades As They Become Available